THE BRIDGING OF NERVE DEFECTS.[1]

A CONTRIBUTION TO THE SURGERY OF NERVES.

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It is difficult to make a satisfactory review of this subject. The operation itself deals with those cases in which approximation of the divided nerve segments—simple nerve suture—is impossible; but we know that ordinary neurorrhaphy, primary or secondary, is not invariably successful, for it happens only too often that under favorable conditions of approximation the functional result is far from perfect. In the present state of our knowledge it is not easy to give the percentage of failure in suture with good approximation, so that in attempts at bridging incoercible separation of the divided ends of a nerve we are uncertain as to how much of the success or failure depends upon factors which are not under the control of the operation itself. In other words, given a case in which some form of attempt at bridging has failed, it is impossible to say that a good functional result would have been secured had perfect approximation been obtained.

Other difficulties are referable to the manner in which the subject of nerve suture is treated in medical literature. The Index Medicus has no classification of it, and the writer[2] has endeavored to consult all of the sections which might bear indirectly thereon. Most of the studies on nerve surgery are hidden away in such sections as Operative Surgery, Surgery of the Extremities, Surgery of the Head and Face, etc. Such a condition has a twofold significance, for, while it argues some defect in the method of indexing, it implies at the same time that the subject itself is not one of great importance or interest.

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It might be thought that the enormous amount of material in the domain of surgery of the nervous system collected and published by Chipault should contain everything of interest upon the subject of nerve suture. But the " État actuel de la chirurgie nerveuse" contains no analytical index, and of the large number of references cited in the work which bear upon this subject very many—especially the inaugural dissertations of foreign universities—are inaccessible to the American reader.

Further, it should be emphasized that much of the material comprised in the literature of the subject consists of operations upon animals. Quite a number of authors whose names are mentioned in connection with the work—Vanlair, Assaky, and others—never reported cases in human surgery. Létiévant, who is much quoted for his pioneer work in this field, operated but twice on the human subject, and the result in each case was complete failure.

Finally, a large proportion of the operative cases are reported at a period before the establishment of a permanent result, and at a time when early return of sensation may be explained by collateral nerve supply, and early return of motion may be considered due to vicarious movements of other muscles than those formerly paralyzed. (Peterson.)

The subjects of nerve repair and regeneration, of simple neurorrhaphy,—primary and secondary,—and of the more simple and obvious means of approximation of the divided ends of nerves, such as stretching and posture, are fully discussed in a somewhat abundant literature, as are likewise such allied procedures as neurolysis, the implantation of a healthy nerve into the nerve of a paralyzed muscle, and the after-treatment of nerve suture, however performed, by electricity and massage.

On the other hand, the more unusual resources for restoring the continuity and functions of severed nerves have a relatively small literature, at least so far as attempts at considering the entire field in a single paper are concerned. Individual case reports abound, and in some of these attempts are made to consider the subject of bridging defects at some length, but actual monographic studies are but little in evidence.

In Chipault's "Chirurgie opératoire du systeme nerveux," 1895, we find a systematic account of this subject, but without a complete list of cases. In the same year Huber made a meritorious attempt to collect all of the recorded cases in which nerve defects were bridged (*Journal of Morphology*). His combined material amounted to some twenty-two cases, over half of which were examples of the grafting of foreign substances.

In 1894, Spijarny published, in an inaccessible Russian journal, a list of nearly 200 cases of nerve suture of all kinds found in literature, and of these thirty concerned the bridging of defects. There were eleven operations of flap-splitting, eleven of foreign grafts, one of implantation, one of *suture à distance,* four of tubulization, and one of resection of bone. This series is of no special value, for some cases are said to be recorded twice, while the tubulizations are in part cases of simple suture with the superaddition of tubulization.

There are also several inaugural dissertations which treat of bridging defects, but the writer has been able to consult only Ehrmann's "Contribution a l'étude de la suture de nerfs à distance," Paris, 1896. This author, while discussing all of the operations for bridging defects, confines his actual material to *suture à distance.*

There are a few monographic studies devoted to particular operations. Thus, Peterson (*American Journal of the Medical Sciences,* 1899) has certainly done all that was possible with the subject of grafting proper, relating twenty histories in all, several of which appear for the first time. Dumstrey, "Ueber Nervenpropfung," *Deutsche Zeitsch. f. Chirurgie,* lxii (1901–2), made a rather unsatisfactory attempt to collect the published cases of nerve implantation, a number being omitted. Ehrmann's thesis on *suture à distance* has already been mentioned; it contains all of the cases (three) of this operation to date (1896). The writer does not learn that the subjects of flap-splitting and resection of bone have ever been submitted to a critical study.

The sections on nerve surgery in Chipault's monumental "État actuel de la chirurgie nerveuse," 1901–1903, contain much material of interest on bridging defects, although this occurs in scattered fashion.

As already intimated, it is doubtful if a complete series of cases of the bridging of nerve defects can be compiled. The plan pursued by Chipault in securing a surgeon from every country in the world to collect the material of his own land has made the list of inaccessible publications much larger than would otherwise be the case. Moreover, a study of the entire material of neuroma would probably lead to the discovery of cases of implantation, etc., which have escaped the compiler. Thus, Maydl and Kukula, who covered the material of Bohemia for Chipault's work, speak of two cases of nerven-plastik as having been done in that country, although details fail.

Excluding all doubtful cases, the material found is as follows: Grafting, 22; flap operations, 11; implantation,* 10; resection of bone, 7; *suture à distance*, 5; tubulization, 1. Total, 56.

Grafting.—In this section the writer will use Peterson's admirable analysis, after first inserting two cases not included therein, one being his own. These are as follows:

Durante (*R. Accad. Med. di Roma*, April 24, 1892), in removing a tumor (osteosarcoma) of the head of the fibula, was obliged to resect a portion of the external popliteal nerve. As it was found to be impossible to approximate the severed ends, he inserted a graft of five centimetres of a dog's sciatic, suturing it in place with catgut. After operation movements of toes and foot notably improved, particularly those of dorsal extension and abduction, sensation also improved. (Report made at the end of a month.) However, rapid recurrence of the malignant growth made it necessary to amputate the leg. Dissection showed that the graft had entirely disappeared. An accurately recorded result is not given. We simply gain the impression that the result was good at an early day after operation. This is a fair illustration of the difficulty which the writer has experienced in judging of the results in the cases found in literature. Generalities abound, but accurately recorded *late* results are scanty.

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* Only those cases are taken in which the operation was undertaken to correct a defect. Cases of implantation for the relief of facial and Duchenne paralysis are not included.

The Author's Case. Nerve Transplantation. Implantation of Four Inches of the Great Sciatic Nerve of a Dog in the External Popliteal of a Man. Result at End of Eight Years.

C. O., a young man of eighteen years, came under my care at the Denver City Hospital, May 10, 1896, with a history of having been run over by a railway train twelve hours before. On examination he was found to have a crush of the right great toe, deep lacerated wounds of the right gluteal region, and a fairly extensive lacerated wound at the outer aspect of the right knee with a compound, comminuted fracture of the head and neck of the right fibula. There was complete anæsthesia and paralysis of the parts supplied by the external popliteal nerve. Dirt and coal-dust were ground into all of the wounds. Under ether the toe was amputated, the gluteal wounds cleaned and sutured, comminuted fragments of the fibula removed, and the lacerated wound at this point trimmed, cleaned, and partly sutured. The popliteal nerve was not found in its usual place below the head of the fibula. An attempt was made to locate its ends, but they were not easily found, and prolonged search was not made. It was thought wise to first gain healing of the wound and then make secondary suture of the nerve. The wound healed in part by primary union, in part by granulation. June 27 it was closed, and on that day nerve transplantation was done as follows:

Ether. Esmarch's bandage. Seven-inch incision at outer aspect of knee. Scar tissue removed. The lower end of the upper fragment of the external popliteal nerve was found without difficulty. It was bulbous. Considerable time was spent in searching for the lower fragment, the peroneus longus muscle being fully exposed. An incision was made in front of the fibula and the anterior tibial nerve was found lying on the extensor longus digitorum. This nerve was traced upward and the external popliteal discovered, its bulbous end being about one-third of an inch above the division of the nerve into the anterior tibial and musculocutaneous. Both bulbous ends were pared; about three and one-quarter inches of space intervened.

During this work, my colleague, Dr. Freeman, had kindly exposed the great sciatic nerve of a thirty-five pound dog. A fragment four inches long was removed, passed between the peroneus longus and the fibula of the patient, and implanted in the external popliteal. Three sutures of fine chromicized catgut were used at each end, one suture being passed through the nerve substance, the other two uniting the sheaths. The fragment was slack and the ends lay in perfect approximation. The external wound was sewn without drainage, the knee placed at an angle of 135°, and a large aseptic dressing with plaster-of-Paris splint applied. Primary union. The knee was confined for a month.

Just before operation, the patient was examined by Dr. J. T. Eskridge, neurologist to the hospital, who reported anæsthesia of the skin area, supplied by the external popliteal nerve together with complete paralysis of its muscles. According to notes made at the time, Dr. Eskridge examined him again on July 20, saying that the anæsthetic area remained about the same as before the operation. August 4 he says, " Temperature, pressure, pain sensations, and ability to recognize cold substances have returned over the entire anæsthetic area. Tactile and localization sensations and ability to recognize warm substances are a little impaired. All forms of sensation are delayed." Under date of August 11 he says, " All forms of sensation normal." On August 13 Dr. Eskridge reported that the tibialis anticus and peroneus longus would not respond to the strongest faradic current.

At this time the patient left for his home in Michigan. I did not hear of him again until April of the following year, at which time Dr. Reuben Peterson kindly examined him, and reported as follows under date of April 3, 1897:

" Patient can feel the touch of a pencil over the entire leg and foot, but sensation is somewhat diminished over an area three or four inches long by a couple of inches wide at the external part of the lower third of the leg, and on the internal aspect of the instep down to the scar made by the removal of the great toe. There is considerable atrophy of the muscles of the leg in the upper third. Circumference of the right leg, eleven inches; left, twelve inches. Middle of calf, twelve inches on the left leg; eleven inches on the right leg. Upper third, right, seven and three-quarters inches; left, eight and one-quarter inches. Abduction of foot impossible. No movement of toes except those controlled by extensor tendons. First and second toes somewhat contracted. Unable to hold foot up. Has good movement in walking, except that he has to lift right leg higher than the other to keep the toes from dragging. I should say that the result is good as far as sensation is concerned, but negative as regards motion. The muscles fail to react to electricity." Another operation was at this time advised, but declined.

A further report on the case was courteously made by Dr. Richard R. Smith, of Grand Rapids, Michigan, August 31, 1903, seven years after operation. Dr. Smith writes as follows:

" There is a very decided atrophy of the anterior muscles of the leg. The patient is unable to flex the tarsus upon the leg in the slightest degree, nor is he able to extend the phalanges of the toes. There is complete paralysis of the tibialis anticus, the extensor proprius pollicis, the extensor longus digitorum, the peroneus longus and brevis. There is partial anæsthesia over the area supplied by the peroneal nerve."

The end result in this case is, then, a complete failure as regards motion, and this in the face of conditions which seemed to promise a good result. The ends of the implanted fragment were carefully approximated, the sutures suitable, wound healing was perfect, and the fragment stayed in.

Summary of Twenty-two Cases of Nerve Grafting.—

1. Case dismissed too early to record result.
2. Implanted segment came away necrotic.
3. Case dismissed too early to record result.
4. Negative at end of one year.
5. Sensation began to return in two months. Motion not recorded.
6. Suppuration. No improvement at end of two months.
7. Sensation good at end of five weeks. Motion indefinitely recorded.

8. At end of ten weeks an indefinite result is recorded.

9. At end of two years sensation "dull;" motion fair.

10. Motion and sensation (median) practically restored at end of six years.

11. Case reported too soon (sixteen days).

12. At end of three months, ulnar. Sensation hardly complete. Motion indefinite.

13. At end of eight months. Motion fair. Sensation not noted.

14. Reported too soon to be of value (thirty-six hours).

15. Sensation returned (fifteen days?), but motion did not.

16. No result at end of two and three-quarters months.

17. No result at end of three years.

18. No improvement.

19. "Good" result at end of two years. (Median.) Sensation good; hand "lame but useful."

20. One and one-half years after operation (at end of four months patient froze hand, losing distal phalanges of first and third fingers). Sensation nearly normal. Hand used daily in work; fine movement of it impossible; some atrophy of muscles.*

21. Short time—leg had to be amputated—motion as well as sensation seemed to be returning. (Durante.)

22. Author's case. Reported at end of eight years. Failure.

As Peterson's paper is readily accessible, the reader is referred to it for details. The writer has added to the twenty cases there recorded that of Durante and his own. These seem to give three "good" results (Cases 10, 19, 20) and three which may be termed "fair" (Cases 9, 13, 21). Twenty-two per cent. of the cases operated on may be said to have terminated in a satisfactory way, although in most of these the final result is not recorded with the detailed accuracy desired by one who would analyze them. One is forced to say that he questions the authenticity of some of the results accounted " satisfactory."

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* A recent letter from Dr. Peterson reports this patient as being at this time "perfectly well as regards the use of his hand."

To this must be added the claims of various surgeons and experimenters that a piece of nerve has no intrinsic superiority as a graft to any other kind of organized tissue, and that given proper isolation of the divided ends from the surrounding tissue a bridge of any sort—a bundle of catgut loops for example—is sufficient to permit of the regeneration of the nerve.

The writer, in studying this branch of the subject, concludes that nerve transplantation should be discarded.

Flap Operations.—While several forms of neuroplasty have been proposed, the principle of all is the same, viz., a portion of the central or peripheral (or both) ends is partly detached, turned back, and united to the other end or flap. The principles underlying these operations, the technique, etc., have been fully described in text-books and monographs. (De Forest Willard.)

The writer herewith briefly recapitulates the cases found by him in literature.

1. Létiévant, the deviser of the operation, experienced failure in his only case in human surgery. (See Chipault's " Operative Surgery of the Nervous System," 1895.)

2. Dittel, another early operator, reported a failure (*ibid.*).

3. Wölfler (" Neugebauer, Neurorraphie u. Neurolyse," *Beiträge z. klin. Chirurgie,* xv, 1895) did a neuroplastic operation after injury to the radial; the patient shortly disappeared from view.

4. Tillmann's case reported in Chipault's " Operative Surgery of the Nervous System," neuroplasty of median and ulnar nerves, success.

5. Gleiss—same reference—successful neuroplasty of ulnar.

6. Brenner (*Wien. klin. Wochen.,* 1891). This case is remarkable in that operation was performed ten years after original injury. A flap operation was done upon the median nerve with a good ultimate result.

7. Bobrow (1893, cited by Spijarny, original journal inaccessible). Excision of tumor involving sciatic in elderly man. Flap operation. Return of sensation and of use of flexors of knee (?).

8. Giordano (*Clinica Chirurgica,* March, 1899). This surgeon, in removing a tumor of the neck, was obliged to resect four centimetres of the vagus, the defect being overcome by a flap operation. Patient lived a year. For a short time after the operation he coughed at times.*

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* This case should really be discarded, for it is known that the vagus of one side may be resected with comparative safety.

9. Von Bruns (*Allegem. Zeitsch. f. Psychiatrie,* Band lii (1895–6). This surgeon operated upon an infant aged two months for congenital neurosarcoma of upper arm involving ulnar and median. No attempt to restore continuity of nerves until a year had elapsed, when, to overcome the paralysis, a flap operation was performed on both nerves. Under appropriate after-treatment there was an excellent return of function in the domain of the ulnar and a partial return in that of the median.

10, 11. The writer has not access to the cases of Lossen (Hueter-Lossen, Grundrisse d. Chirurgie, seventh edition, 1896) and Gundt (Inaug. Dissert., Berlin, 1897). He gathers the impression that these cases were successful.

Of these eleven cases five are discarded as having been reported too early or as lacking in detail. Of the remaining six, two were failures and four complete or partial successes.

Implantation or Anastomosis.—The ten cases in which defects in the continuity of nerves were overcome in part by anastomosis are as follows:

1. KENNEDY (Vol. ii of Chipault's "État actuel," etc.). In one case, Kennedy implanted the central ends of the median and ulnar into the radial. Result negative.

2. DESPRES (cited by Dumstrey) implanted an injured median into the ulnar and obtained a "fine result."

3. GUNN (cited by Dumstrey) sutured the distal end of the ulnar (after removing a neuroma) into the median. Sensation returned; no report as to motion.

4. SICK (cited by Dumstrey) sutured the radial to the median; eighteen months later there was an excellent result as to both motion and sensation.

5. NEUGEBAUER (sometimes quoted as Wölfler's case, cited by Dumstrey). After scar excision for contracture (bend of knee) peroneal paralysis was noticed. Anastomosis between the peroneal and (assumed) internal popliteal. Result negative eight months later.

6. DUMSTREY (*loc. cit.*) implanted the ulnar into the median and got partial return of motion and sensation.

7. TRZEBICKY (cited in Chipault's "État actuel," etc.) sutured both ends of external popliteal to internal popliteal. Result satisfactory.

8. TRZEBICKY (*v. supra*), after resecting median (?) for sarcoma, implanted central (?) end into ulnar. Result satisfactory.

9. TRZEBICKY (*v. supra*), after resecting the ulnar for sarcoma, implanted its central (?) end into the median. The primary result was satisfactory, but the patient soon died of metastases.

10. CODEVILLA (*Clinica Chirurgica,* 1900, Nos. 9, 10). In a case in which the outer side of the knee was crushed, with the peroneal nerve

involved in the scar, the peripheral end of the latter was grafted into the internal popliteal. No improvement followed.

The results may be considered encouraging in five or six cases out of the ten (fifty per cent.).

Resection of Bone.—Since it is a foregone conclusion that if a divided nerve can best be made to heal under favorable conditions of approximation, and that removal of a segment of long bone will permit this approximation and guarantee the restoration of nerve continuity, it will be seen that the only practical question involved is "when is it justifiable to resect bone for this purpose?" It is not easy to answer this. The writer has found notes of seven cases, in the majority of which the bones were injured in the original traumatism which involved the nerve. In one of Keen's two cases resection was undertaken for false-joint following fracture. The references are as follows:

Keen (two cases), in Chipault's "État actuel," etc.; Rose and Carless ("Text-Book on Surgery"), and the older cases cited by Huber and other systematic writers (Lewin, Löbker, Bergmann, Wheeler).

Suture à Distance.—This consists essentially of bridging a defect with loops of catgut, etc. The positive results of Glück and Ehrmann are sufficiently well known. Recently, Keen (in Chipault's "État actuel," etc.) has reported a case with negative result.

Tubulization.—Although this method is extensively quoted in literature, the writer is able to find but one case in which it has been used to favor the restoration of nerve continuity to the exclusion of other resources. To promote nerve regeneration along the natural paths, surgeons have made use of barriers to prevent the fusion of nerve substance with the surrounding tissues. This is recorded many times in cases of simple nerve suture. So far as it refers to the principal method of securing continuity, the writer knows only of the case of Guelliot; this is cited by Ehrmann and others. As it resulted negatively, he judges that the theoretical operation of van Lair has never assumed a definite status in practice.

General Conclusions.—Although correction of the evils resulting from a gap in the continuity of a nerve is a matter of great importance in a given case, it hardly seems possible at this time to say definitely what form of bridging should be employed. More cases, and especially cases recorded later and better, are needed. Neuroplasty and implantation (anastomosis) are always available resources, and for the present it would seem that they should be preferred. Resection of bone may be advisable in selected cases. Transplantation of foreign grafts should be abandoned. It is hardly necessary to say that prognosis in an individual case should always be guarded, and that repeated operations may be necessary.